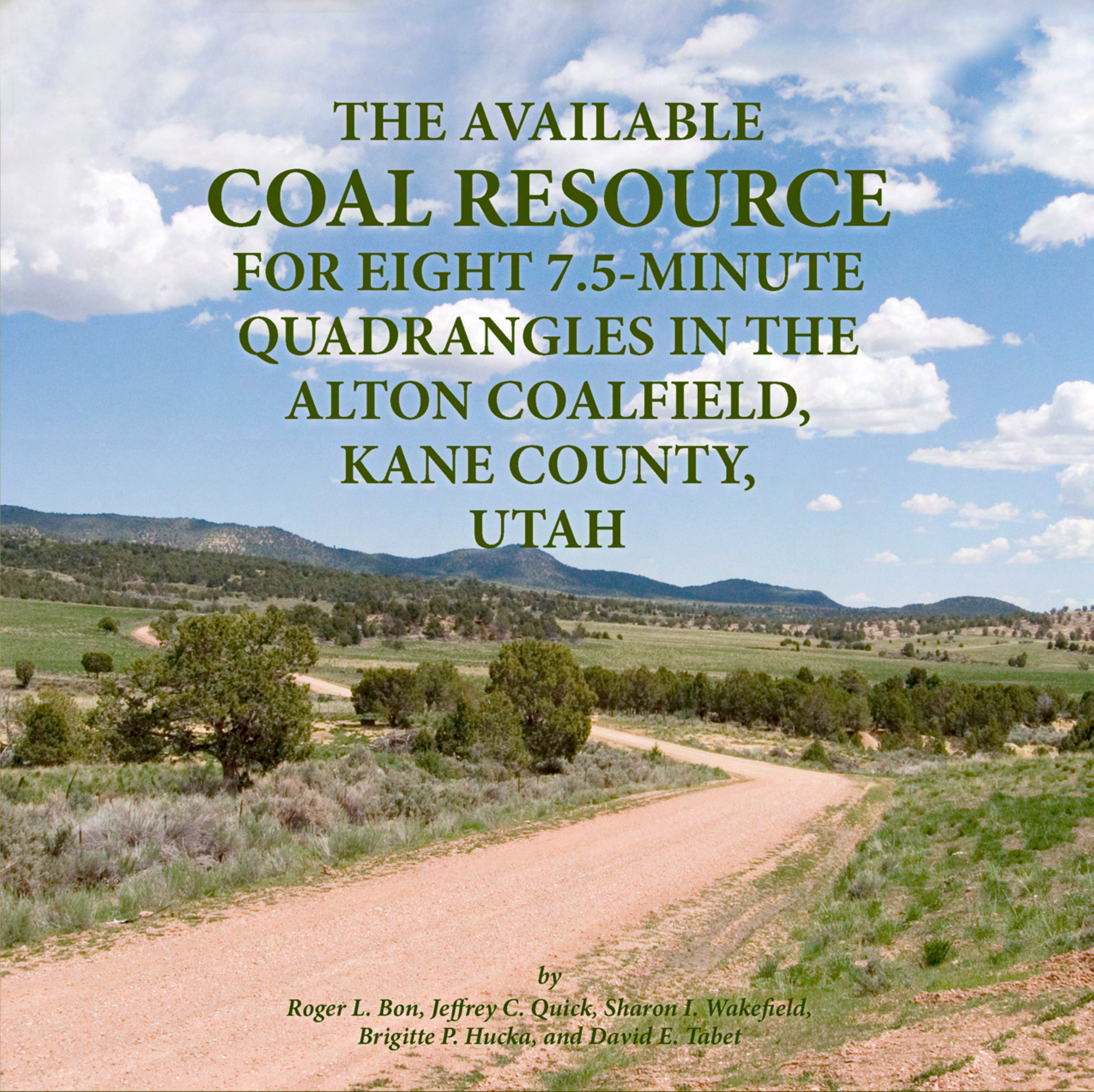

THE AVAILABLE COAL RESOURCE FOR EIGHT 7.5-MINUTE QUADRANGLES IN THE ALTON COALFIELD, KANE COUNTY, UTAH

by

Roger L. Bon, Jeffrey C. Quick, Sharon I. Wakefield, Brigitte P. Hucka, and David E. Tabet

UTAH DNR GEOLOGICAL SURVEY

SPECIAL STUDY 118
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2006

THE AVAILABLE COAL RESOURCE FOR EIGHT 7.5-MINUTE QUADRANGLES IN THE ALTON COALFIELD, KANE COUNTY, UTAH

by
Roger L. Bon, Jeffrey C. Quick, Sharon I. Wakefield, Brigitte P. Hucka, and David E. Tabet

Cover photo: View of Alton amphitheatre southeast of the town of Alton. Photo by Mike Vanden Berg.

ISBN # 1-55791-757-4

2006

SPECIAL STUDY 118
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

STATE OF UTAH

Jon Huntsman, Jr., Governor

DEPARTMENT OF NATURAL RESOURCES

Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY

Richard G. Allis, Director

PUBLICATIONS

contact

Natural Resources Map/Bookstore

1594 W. North Temple

Salt Lake City, UT 84116

telephone: 801-537-3320

toll-free: 1-888-UTAH MAP

website: http://mapstore.utah.gov

email: geostore@utah.gov

THE UTAH GEOLOGICAL SURVEY

contact

1594 W. North Temple, Suite 3110

Salt Lake City, UT 84116

telephone: 801-537-3300

fax: 801-537-3400

website: http://geology.utah.gov

TABLE OF CONTENTS

FIGURES

TABLES

THE AVAILABLE COAL RESOURCE FOR EIGHT 7.5-MINUTE QUADRANGLES IN THE ALTON COALFIELD, KANE COUNTY, UTAH

by
Roger L. Bon, Jeffrey C. Quick, Sharon I. Wakefield, Brigitte P. Hucka, and David E. Tabet

ABSTRACT

Approximately 2.91 billion tons of coal are available for mining in the Alton (formerly Kanab) coalfield, Utah. This includes about 503 million tons (17%) of surface-minable coal and 2.41 billion tons (83%) of underground-minable coal. Thirty percent of the available coal identified in this study is a demonstrated resource (within 0.75 miles of a measurement location) and the remainder is less reliably identified.

The available coal resource of the Alton field includes two Dakota Formation coalbeds, the (lower) Bald Knoll and (upper) Smirl beds. Maps and associated tables showing the distribution and quantity of the available coal are provided for each coalbed in the appendix. Sixty-four percent (1.88 billion tons) of the available coal is in the Smirl coalbed, and 36% (1.04 billion tons) is in the Bald Knoll coalbed. Coal rank is subbituminous A, increasing slightly in Btu value to the west. Average sulfur content is 1% or more for both beds, which for power plant emission is more than 2 pounds sulfur per million Btu in both coalbeds, but the sulfur content is markedly lower in the Bald Knoll bed. Available data show that the in-ground coal averages 13 pounds mercury per trillion Btu.

Considering coalbed thickness (4- to 14-foot-thick beds), distribution, and current mining practices (down to depths of 3000 feet), we estimate that about 1.25 billion tons of the 2.91 billion-ton available coal resource might be recovered from the Alton coalfield. This tonnage is sufficient to satisfy Utah's current coal consumption for about 50 years.

INTRODUCTION

From the 1870s through 2004, Utah coal mines produced more than 906 million tons of coal, of which no more than 70,000 tons came from the Alton (formerly Kanab) coalfield (Grose and others, 1967; Vanden Berg, 2005). Although the coalfield accounts for less than 1% of Utah's cumulative coal production, its substantial in-ground coal resource and proximity to central Utah and southern Nevada power plants indicate that production from the Alton coalfield could become increasingly important. This study provides an estimate of the amount and distribution of the available coal resource in the Alton coalfield. Results of this study will be useful to government agencies, industry, landowners, academic workers, and environmental advocacy groups.

We used a Geographic Information System (GIS) to identify and measure the available coal resource in the Alton coalfield. Resource and other units used in this report are in U.S. customary units; table 1 provides conversion factors to the International System of Units.

Table 1. *Selected conversion factors between U.S. customary units used in this report and the International System of Units; modified from Hyland and Lund (2003), IEEE (1997), and ASTM (1990).*

To convert from unit (abbreviation)	**To** unit (abbreviation)	**Multiply by**
inch (in)	meter (m)	0.0254[a]
foot (ft)	meter (m)	0.3048[a]
mile, statute (mi)	kilometer (km)	1.609
pound (lb)	kilogram (kg)	0.45359237[a]
ton[b] (st)	metric ton (t)[c]	0.9072
British thermal unit per pound (Btu/lb)	megajoule per kilogram (MJ/kg)	0.002326[a]
square mile (mi^2)	square kilometer (km^2)	2.590
acre-foot (acre-ft)	cubic meter (m^3)	1233.5
cubic foot (ft^3)	cubic meter (m^3)	0.02832
pound per million Btu (lbs/10^6 Btu)	microgram per joule (µg/J)	0.430 0
pound per trillion Btu (lbs/10^{12} Btu)	picogram per joule (pg/J)	0.430 0

[a] an exact conversion
[b] a short ton (2,000 lb)
[c] a commercial term (1,000 kg)

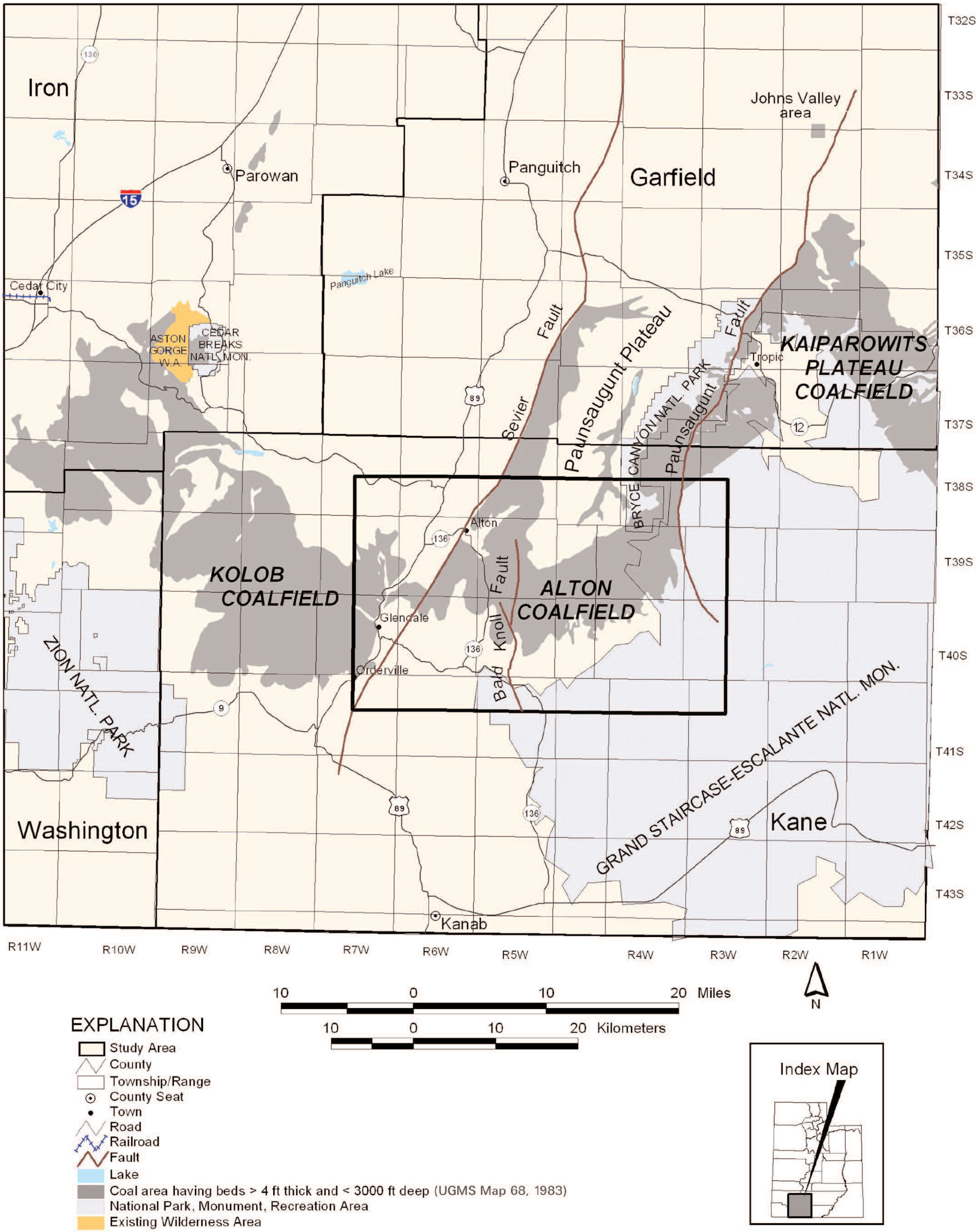

Figure 1. *Location of the Alton coalfield study area, Kane County, Utah.*

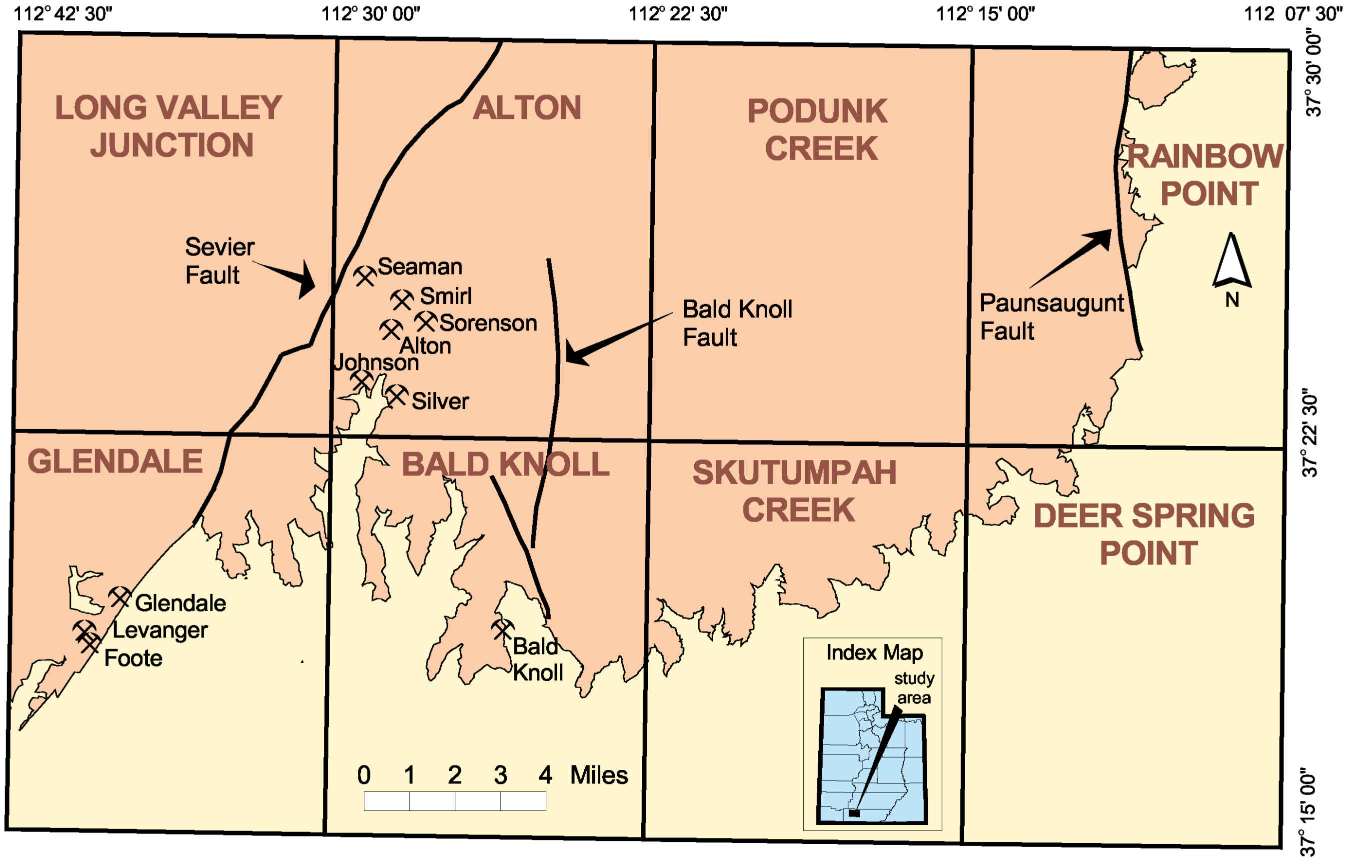

Figure 2. *Index showing the eight 7.5-minute-quadrangle study area including the locations of major faults, abandoned coal mine portals, and the extent of the coal-bearing Dakota Formation in the Alton coalfield, Utah.*

Location and General Geology

The study area (figure 1) covers about 465 square miles within central Kane County. The study area is defined by the eight 7.5-minute quadrangles shown in figure 2, and encompasses nearly all of the Alton coalfield. The Sevier fault separates the Alton coalfield from the Kolob coalfield on the west, and the Paunsaugunt fault separates most of the Alton field from the Kaiparowits Plateau coalfield on the east. A small portion of the Alton coalfield, the area south of Tropic, Utah, lies to the east of the Paunsaugunt fault (figure 1). The Alton coalfield underlies the Paunsaugunt Plateau.

The ground surface in the Alton coalfield ranges from about 6000 to 9400 feet (ft) above sea level. Most of the minable coal occurs at elevations between 6500 and 7500 ft above sea level (Doelling, 1972).

U.S. Highway 89 runs along the western edge of the Alton coalfield west of the Sevier fault. State Route 136 branches eastward from U.S. Highway 89 and serves the town of Alton. Glendale and Orderville are the only other communities in the study area (figure 1). No railroads serve the Alton coalfield, and the nearest rail is at Cedar City, about 40 miles to the west.

The Alton coalfield lies along the gently dipping southern flank of the Paunsaugunt Plateau. The northerly dips of the coal-bearing strata are generally less than two degrees over most of the study area, but are locally steepened by drag caused by the Sevier and Paunsaugunt fault zones. A gentle synclinal fold runs down the center of the Paunsaugunt Plateau and modifies the general northerly dip of the strata in the study area. The north-south trending Bald Knoll fault cuts the central portion of the coalfield (figure 2). The vertical displacement along this down-to-the-east normal fault is over 400 ft near its southern end, but decreases to the north. The two major bounding fault zones on the eastern and western sides of the Alton coalfield both have down-to-the-west displacements ranging from 100 to 2000 ft; the displacement along the Paunsaugunt fault generally increases to the north (Doelling, 1972).

The Upper Cretaceous Dakota Formation is 450 ft thick on the western side of the Alton field and unconformably overlies the Jurassic Carmel Formation, whereas on the eastern side of the field the Dakota thins to about 150 ft and overlies the Jurassic Entrada Sandstone (Doelling, 1972). For this study, two coalbeds were mapped in the Dakota. In ascending order, these coalbeds are designated the Bald Knoll and Smirl. The average thickness and distribution of the two coalbeds within the study area is shown in table 2. Throughout the study area, the Smirl bed averages 13.6 ft thick and tends to be thicker on the west side of the study area. The Bald Knoll bed lies, on average, about 187 ft below the Smirl and averages 6.8 ft thick. The Bald Knoll bed is thicker within the Bald Knoll quadrangle (10.7 ft average thickness) and thins to the north (6.4 ft average thickness in the Alton quadrangle) and east (3.0 ft average thickness in the Deer Spring Point quadrangle).

Prior to the mid-1960s, studies of the Alton (then

Table 2. Average overburden, interburden, and coalbed thickness in feet by 7.5-minute quadrangle for the Smirl and Bald Knoll coalbeds in the Alton coalfield study area.

7.5-minute Quadrangle	Smirl depth	Smirl thickness	Smirl count	Interburden	Interburden count	Bald Knoll depth	Bald Knoll thickness	Bald Knoll count
Alton	106	15.9	115	203	16	406	6.4	16
Bald Knoll	87	14.1	59	187	8	198	10.7	28
Deer Spring Point	83	13.3	13	162	3	260	3.0	3
Glendale	202	12.5	3		0			0
Podunk Creek	405	10.5	2		0			0
Rainbow Point	129	10.7	36	160	7	214	3.6	15
Skutumpah Creek	122	13.8	106	179	8	243	3.2	15

count = number of measurements

Kanab) field's coal resources termed the lower conglomeratic part of the Dakota the "Dakota Sandstone" and included the Dakota Formation's upper coal-bearing section as part of the Tropic Shale (Richardson, 1909; Gregory, 1951; Cashion, 1961; Cohenour, 1963; Robison, 1963a, 1963b, 1964; Grose and others, 1967). Thus, discussions of the coal resources of the "Kanab" field talked of coal resources in the Tropic Shale. Based on mapping, lithologic sequences, and paleontologic zonation, Lawrence (1965) redefined the Dakota to include the coal-bearing section. Doelling (1972) was the first to perform a comprehensive coal resource study of the Alton field using the new Dakota Formation terminology. Gustason (1989), Kirschbaum and McCabe (1992), and Ulicny (1999) discussed recent interpretations of stratigraphy and sedimentologic controls on coal formation in the Dakota Formation of southern Utah.

The Dakota Formation is conformably overlain by the 700- to 1000-ft-thick Cretaceous Tropic Shale, which was deposited at the beginning of the North American Cretaceous marine incursion (Lawrence, 1965). Like the Dakota, the Tropic Shale thickens to the west across the study area. The overlying Cretaceous Straight Cliffs, Wahweap, and Kaiparowits Formations form the escarpment of the Paunsaugunt Plateau and consist of 800 to 2100 ft of continental and nearshore clastic strata. Capping the Paunsaugunt Plateau is 1300 ft of varicolored limestone of the Tertiary Claron Formation that has eroded into marvelous rock sculptures preserved at Bryce Canyon National Park in the northeastern part of the study area. Locally within the coalfield are sporadic Quaternary volcanic cones and basalt flows such as those found at Bald Knoll (Doelling, 1972). Most of the stream courses are filled with Quaternary alluvium, which is particularly thick along Sink Valley and Kanab Creek near the town of Alton.

Mining History

Our review of production records, mine maps, and descriptions of prospects indicates that coal production from the Alton coalfield totaled about 67,850 tons. Complete production records are not available, but the earliest production dates back as far as the 1900s (Richardson, 1909; Grose and others, 1967). Coal production has come from small mines opened close to the towns in the area to provide heat for local residents during the winter months, and the largest of these mines were thus close to Alton. This small-scale coal production probably stopped in the late 1960s, likely due to increased regulation of coal mining. Figure 2 shows the locations of historical coal mines in the study area; most of the coal production has come from the Smirl bed, with smaller amounts from the Bald Knoll bed (table 3). In the early 1960s, large tracts of federal land were leased by Nevada Electric Investment Company and Utah Construction and Mining Company to explore for surface-minable coal to meet growing demand for electricity in the southwestern U.S.

COAL RANK, QUALITY, AND GAS CONTENT

Assay Data

Assay data from 335 coal samples collected from 257 drill holes in the Alton coalfield were used to evaluate the coal rank, quality, and gas content. The data are from the National Coal Resource Data System (NCRDS) database, Utah Geological Survey (UGS) drill-hole records, Doelling (1972), Bowers and others (1976), Bowers (1977), Affolter and Hatch (1980), and unpublished exploration drilling data from Utah International, Incorporated.

Coal Rank

Evaluation of coal assay data collected by different agencies using different collection protocols is challenging (Hower and others, 1989). Utah's arid climate poses an additional difficulty in evaluating the coal assay data from the Alton coalfield since it promotes a commonly unrecognized loss of moisture from coal specimens (Kohler and others, 1997). Both of these problems hinder evaluation of coal rank.

To minimize inconsistencies associated with variation of sampling and analysis protocol, we ignored data corresponding to surface samples, weathered samples, or sam-

Table 3. *Coal mines in the Alton coalfield.*

Mine Name	**UTM N[1]**	**UTM E[1]**	**Coalbed**	**Estimated Tons Mined**	**Years of Activity**
Alton	4,141,020	369,320	Smirl	11,500	1962 – 1970
Foote	4,129,420	358,390	Smirl		1963 – 1964?
Glendale[*1]	4,131,850	359,420	Smirl	2,500	1920 – 1930?
Levanger[*1]	4,130,320	358,260	Smirl		1920 – 1944?
Seaman	4,142,900	368,340	Smirl	?	?
Silver[*2]	4,138,700	369,480	SmirI	200	1906?
Smirl[*1]	4,141,620	369,795	Smirl	51,800	1945 – 1961
Sorensen[*1]	4,141,210	370,310	Smirl	1,250	1940 – 1948
Bald Knoll	4,130,595	373,260	Bald KnolI	?	?
Johnson	4,139,060	368,295	BaId Knoll	600	1907 – 1927?

[1]zone 12, NAD27, Universal Transverse Mercator northing (**UTM N**) and Easting (**UTM E**) coordinates (meters). Data are from Richardson (1909), Grose and others (1967), Doelling (1972), and U.S. Bureau of Land Management files.

[*1]UGS has mine map

[*2]Referenced in Doelling (1972)

ples having more than 40% dry ash, as well as data records that lack sulfur, ash, and Btu values (which are required for calculation of ASTM coal rank). The 40% maximum ash limit is arbitrary but is similar to the 33% ash limit used by Bragg and others (1997) to reduce calculation error related to conversion of data to different reporting bases. We also ignored a few records having unlikely or anomalous values on cross-plots. Ultimately, we selected 335 data records to evaluate the coal quality of the Smirl and Bald Knoll coalbeds in the Alton coalfield.

Btu values on a moist, mineral-matter free basis ($Btu_{m\ mmf}$) were calculated to determine the coal rank (ASTM, 1990). The data show that coal in the Alton coalfield is subbituminous A rank (between 10,500 and 11,500 $Btu/lb_{m\ mmf}$).

Coal Quality

Figure 3 shows that sulfur and ash values on an as-received basis vary within and between the two coalbeds. The Smirl coalbed contains more sulfur (average 1.3 %) than the Bald Knoll coalbed (average 1.0%). Conversely, the average ash content for the Bald Knoll bed (22.7%) is considerably higher than that for the Smirl bed (10.7%).

Mercury emissions from coal-fired electric utilities will be regulated by 2010 (U.S. Environmental Protection Agency, 2005). Accordingly, table 4 summarizes the mercury content of coalbeds in the Alton coalfield. The average mercury content of in-ground coal in the Alton coalfield is somewhat higher than the U.S. average of 13 lbs $Hg/10^{12}$ Btu, and is markedly higher than the average 3.7 lbs $Hg/10^{12}$ Btu observed for in-ground coal from the nearby Wasatch Plateau and Book Cliffs coalfields (Quick and others, 2003).

There are no petrographic data for the Alton coalfield, but Hucka and others (1997) reported 23 petrographic analyses for Dakota coals from the Henry Mountains coalfield, about 80 miles northeast of the Alton area. The Dakota coals from the Henry Mountains coalfield are found near the base of the formation and may be representative of the lower bed (Bald Knoll) in the Alton coalfield. The Dakota coals from the Henry Mountain field contain an average of 51.0% vitrinite, 5.5% liptinite, and 43.5% inertinite.

Table 4. *Mercury content of major coalbeds in the Alton coalfield, Kane County, Utah*

Coalbed	**Bald**	**Smirl**	**Both Beds**
Average mercury content	16.5	16.4	16.4
Median mercury content	15.3	12.1	14.7
Number of data records	3	8	11

Values in lbs $Hg/10^{12}$ Btu

Coalbed Methane

The Alton coalfield is about 120 miles south of the coalbed methane developments of central Utah. In central Utah's Drunkards Wash area, Ferron Sandstone coals have produced more than 200 billion ft^3 of coalbed methane from 470 wells (Lamarre, 2003). No coalbed methane production has been recorded in the Alton coalfield.

Doelling and others (1979) tested 3 core samples for gas content from two locations within the Alton coalfield proper and one from the Johns Valley area slightly north of the study area. The two samples from the Smirl bed both yielded three standard ft^3 of gas per ton coal (scf/ton), and one sample from the Bald Knoll yielded 13 scf/ton. The coal samples' low gas contents may relate to the relatively low rank of the coal.

Three abandoned petroleum wells drilled in the vicinity of the study area in 1963, 1975, and 1984, reported

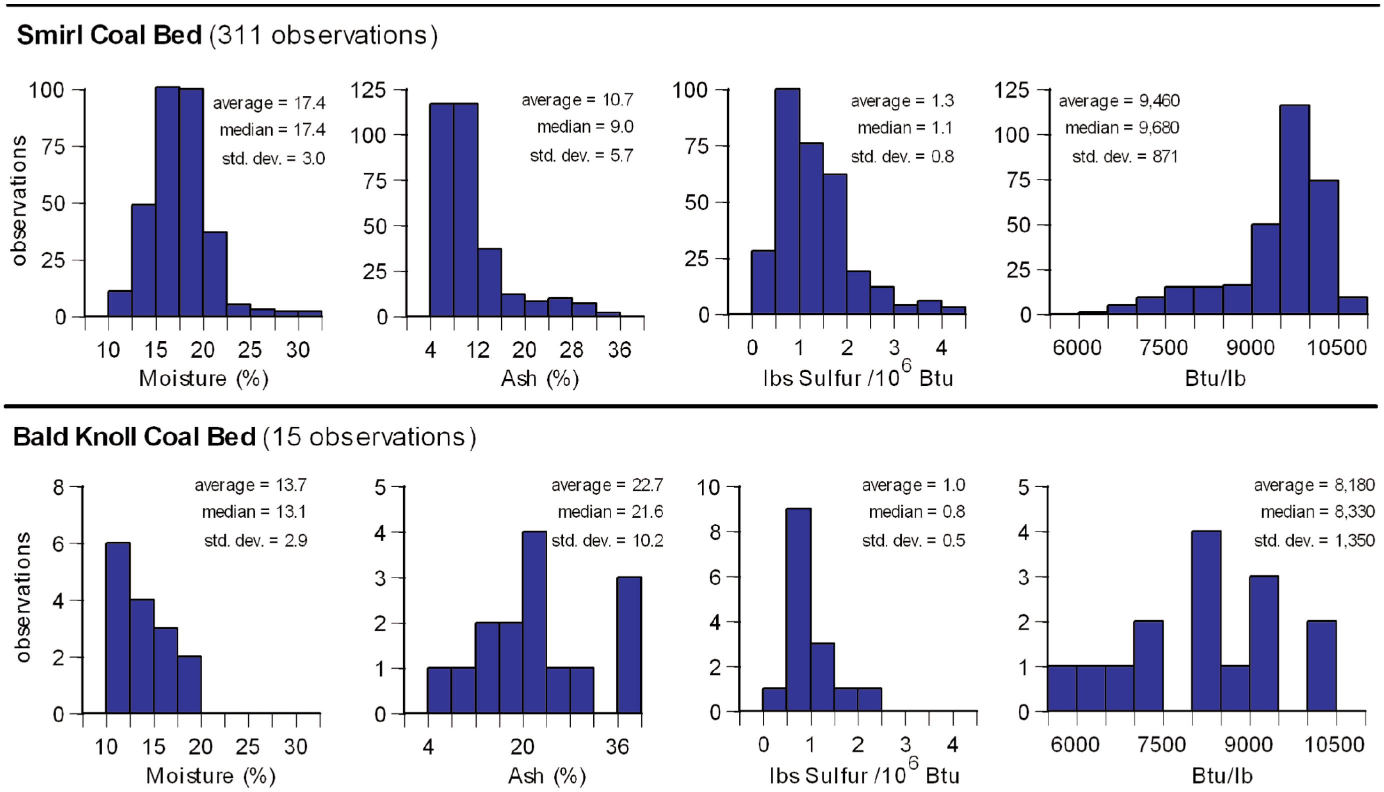

***Figure 3.** Frequency histograms and summary statistics showing moisture, ash, sulfur, and heating values for two coalbeds in the Alton coalfield, Kane County, Utah. The histograms show the absolute frequency distribution of data records (one data record equals one count). Data are on an as-received basis from the NCRDS data base, UGS drill-hole records, Doelling (1972), Bower and others (1976), Bower (1977), Affolter and Hatch (1980), and un-published data from Utah International, Inc.*

shows of gas from the Dakota-Tropic interval. In addition, between 2002 and 2004, Legend Energy drilled four wells near the study area to test for coalbed gas in the Dakota Formation. All four wells were plugged and abandoned and only one well, the Pugh 8 in section 34, T. 38 S., R. 5 W., Salt Lake Base Line and Meridian, had a gas show in the Dakota coals that were cored; no gas desorption data have been released. Although coal beds of sufficient thickness are present in the Alton coalfield, the low rank of the coal and its corresponding low gas content limits the potential for coalbed gas production in this area.

SPATIAL DATA USED TO CALCULATE COAL RESOURCE TONNAGE

Two kinds of spatial data were used to calculate the coal resource of the Alton coalfield. Geographic data are typically electronic or paper maps compiled by various agencies. We used these maps to evaluate the impact of geologic, geographic, and land-use features on coal mining. Stratigraphic data are numeric data sets that list coalbed thickness and depth values together with drill hole location coordinates; we used these data to create new maps showing the thickness, extent, and depth of coalbeds.

Geographic Data

Our study used digital maps of perennial streams, lakes, roads, and municipalities from the Utah Automated Geographic Reference Center (UAGRC, 2005), as well as U.S. Geological Survey (USGS) digital elevation models with 10-meter grid cells. To speed the resource calculation time, the digital elevation models were converted from 10-meter grid cells into 30-meter grid cells. No railroads, pipelines, or power lines occur in the study area. No mine maps could be found for the Alton, Bald Knoll, Foote, Johnson, Seaman, or Silver mines; only the Glendale, Leavenger, Smirl, and Sorensen mines had maps. Data for oil and gas wells are from the Utah Division of Oil, Gas and Mining (UDOGM, 2005). Fault locations were taken from the 1:500,000 scale, digital geologic map of Utah (Hintze and others, 2000).

Stratigraphic Data

Coal exploration drill-hole data listing the thickness and depth of coalbeds are from various sources; many of the data records are from electronic files compiled by the UGS for the NCRDS. Original sources of the drill-hole data include records from Doelling (1972), Bowers and others (1976), Bowers (1977), UGS files, and data donated by Utah International, Inc. Coal thickness data from 422 drill holes (figure 4) were used in this study. One hundred thirty-eight field observations of coalbeds were used to confirm outcrop locations derived from the intersection of coalbed structure maps with digital surface elevation model information. About 20 of the outcrop coal thickness values were used for stratigraphic control in areas without drill-hole data.

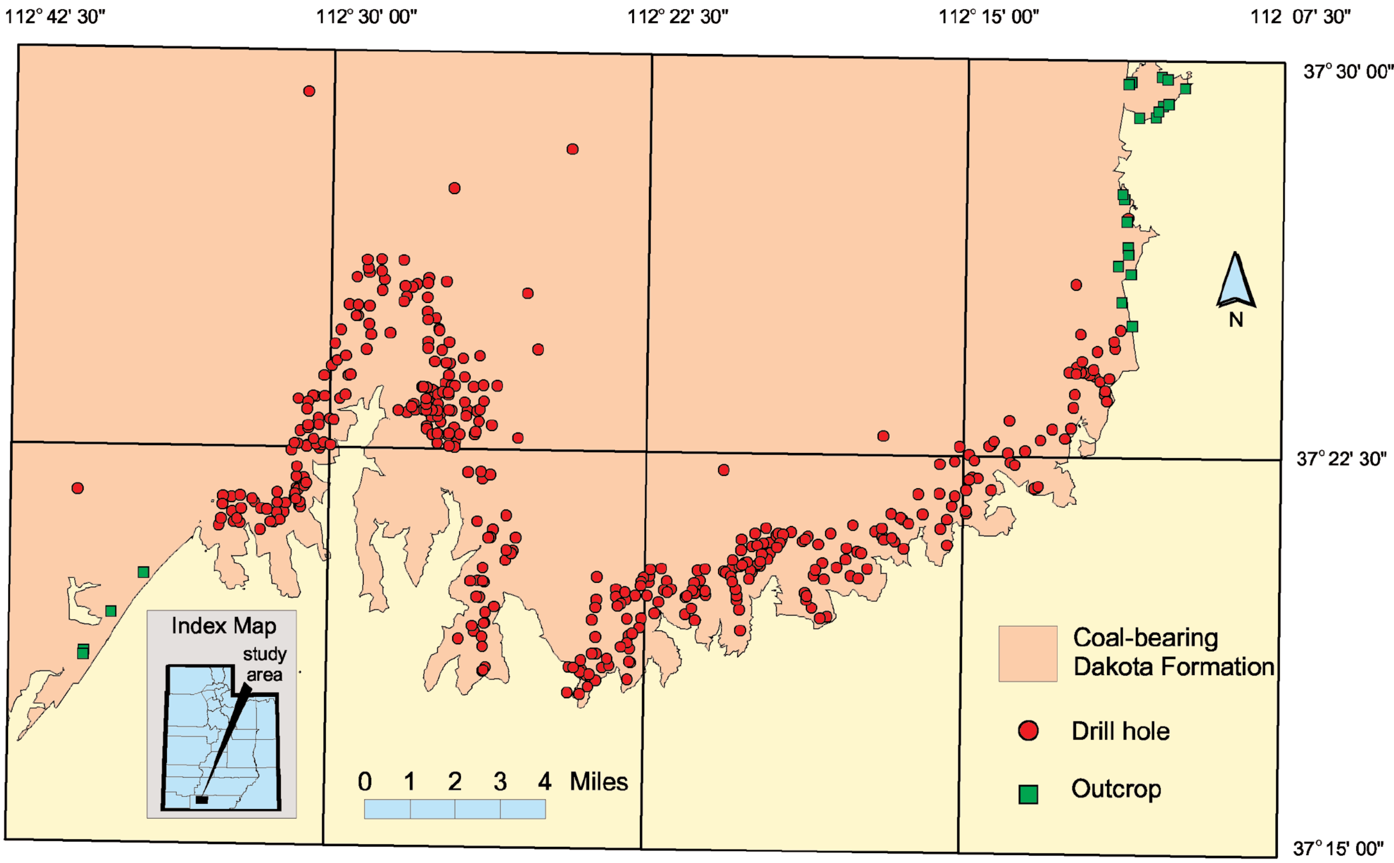

Figure 4. *The location of 422 drill holes and 20 coal outcrops in the study area. Data for each drill hole include the depth and thickness of one or more coalbeds. Drill holes that are adjacent to the study area were included in the analysis to improve the reliability of derived maps near the edge of the study area, but are not shown on this map.*

METHOD USED TO CALCULATE COAL RESOURCE TONNAGE

Calculation of the in-ground coal tonnage requires knowing the areal extent, thickness, and density of each coalbed. Values for the areal extent and thickness for each coalbed were entered into a spreadsheet where the coal tonnage was calculated using a coal density value of 1770 tons per acre-ft of coal (Wood and others, 1983). For example, GIS analysis revealed 7891 acres where the available, underground-minable coal in the Smirl coalbed is between 7 and 8 ft thick. The spreadsheet calculation below shows there are 105 million tons of 7- to 8-ft-thick coal in the Smirl coalbed that are available for underground mining.

$$7891 \text{ acres x } 7.5 \text{ ft coal x } \frac{1770 \text{ tons coal}}{\text{acre - ft}} = 104{,}756{,}000 \text{ tons coal}$$

Creating Maps Using ArcView

As noted earlier, many of the maps used in this study were previously complied by various agencies. However, some were newly created. This section describes how these latter maps were made.

We created maps showing coalbed thickness, depth, and interburden thickness from drill-hole data using the Spatial Analyst (v.1.1) extension for ArcView (v.3.2) software. The calculations are based on identically registered, 30-meter grid cells (0.2224 acres) using zone 12, NAD83, UTM coordinates (meters). Coalbed thickness and interburden maps were made using a fourth-order, six-nearest-neighbor, inverse-distance mapping function. Coalbed depth and elevation maps were made using a tension, six-nearest-neighbor, spline mapping function. The intersection of the coalbed elevation and surface elevation defined the coalbed outctrop, which we verified by comparison to digitized outcrop lines from Doelling (1972).

Coalbed Thickness Maps

Coal oxidation and burning near the outcrop often reduces the thickness of coalbeds in Utah. Burning can also cause slumping of overlying sediments, which further reduces the apparent coalbed thickness at the outcrop (Doelling, 1968). Thus, outcrop observations in Utah are rarely representative of the amount of coal buried behind the outcrop. Because we have information from numerous drill holes (figure 4), we ignored all but about 20 outcrop thickness observations.

Some coalbeds in the Alton coalfield consist of several adjacent beds separated by one or more feet of rock parting. If such coalbeds can be mined by surface (open-pit) methods the adjacent beds can be successively exposed and recovered. However, if the coal is buried deeply, underground mining methods are required and only one of the adjacent beds can be recovered. Consequently, the available coal resource depends on the mining method. To account for the effect of the mining method on the available coal resource, coal thickness maps were constructed in two different ways. Coalbed thickness maps for surface-minable coal were constructed to include all coalbeds between 20 and 200 ft deep and more than one foot thick; these maps include coal in adjacent splits, riders, and sub-beds. Coalbed-thickness maps for underground-minable coal were constructed to include only those parts of the bed more than 200 ft deep that might be recovered using underground mining methods; these maps exclude coal in thinner splits, riders, and sub-beds that are separated from the thickest bed by more than one foot of rock.

Identifying the underground-minable part of a coalbed is not simple where numerous partings, splits, riders, and sub-beds occur. Accordingly, we used some arbitrary but consistent rules to distinguish the underground-minable part of a coalbed. For our maps of the underground-minable coal resource, the thickness of the coalbed was truncated at partings that are more than one foot thick. This convention generally excluded coal in riders and sub-beds. Note that an underground-minable interval sometimes included rock partings that were less than one foot thick if the coal above or below a parting was at least twice the thickness of the included parting.

Although thickness values for surface-minable and underground-minable coal were obtained using different tabulation methods, maps of both surface- and underground-minable coal were made using the same inverse-distance, mapping function. To avoid double counting coal tonnage, we excluded areas having surface-minable coal from subsequent mapping of the underground-minable coal. Coalbed thickness maps for the Bald Knoll and Smirl beds are included in the appendix.

Coalbed Depth Maps

Depth maps were made for tops of coalbeds encountered in the 422 drill holes in the project area; areas on the east side and west side of the Paunsaugunt Plateau were mapped independently because of the large displacement on the Sevier and Paunsaugunt faults. Subtraction of the newly created depth map from surface elevations obtained from the USGS digital elevation model allowed us to construct an elevation (structure) map for both coalbeds. Coalbed depth to the top of the Smirl bed is included in the appendix. Generally, except for coal resources west of the Sevier fault, the depth of coal increases with increasing topography northward from outcrop. Between the two major fault zones, the Smirl coal zone reaches a maximum depth of approximately 3200 feet in several small isolated pods, and is generally less than 2500 feet deep over most of the area.. West of the Sevier fault, the Smirl zone is found at depths ranging from a few feet at outcrop to more than 5500 feet at the north end of the coalfield along the west side of the Sevier fault boundary. The Smirl zone is approximately 2500 feet deep under Bryce Canyon National Park.

Coalbed Interburden

The thickness of sediment between adjacent coalbeds (the interburden) is significant because two beds having less than 40 ft of interburden cannot both be mined safely by underground mining methods. The interburden between the Bald Knoll and the Smirl beds is nowhere less than 40 ft and averages about 187 ft, so both beds could be mined throughout the study area. As a result, no interburden maps were constructed.

RESOURCE CLASSIFICATION

The USGS (Wood and others, 1983) narrowly defines a coal reserve as coal that can be economically produced at the time of determination, whereas a coal resource is broadly defined to include coal for which economic extraction is potentially feasible. In this study, we did not rigorously consider coal-production costs, the percent of the in-ground coal that can be recovered, or other factors required to estimate a coal reserve. Instead, we identified a subset of the in-ground coal resource, which we call the available coal resource.

The Available Coal Resource

The available coal resource is that part of the total coal resource remaining after subtraction of coal in areas affected by past mining, or where mining is prohibited because of technical or land-use restrictions. These restrictions vary from place to place (Eggleston and others, 1990).

Restrictions to mining are considered in two groups. Technical restrictions limit mining to areas where the coal can be safely recovered using current technology. Land-use restrictions limit mining to areas where mining will not harm human infrastructure or environmental assets. Table 5 lists the land-use and technical restrictions that are used in this study, together with their associated buffers and restriction factors. Some of the restrictions are specific to surface-minable coal, some are specific to underground-minable coal, and some apply to both.

Restrictions for Underground-Minable Coal

All active Utah coal mines are underground mines, and most use continuous mining machines to develop mains and entries, and longwall mining machines for bulk production. Longwall machines used in Utah are usually designed for 6- to 14-ft-thick coalbeds. In the eastern U.S., underground coal mines sometimes work beds as thin as 2 or 3 ft. However, this is done only where some special circumstance or use of the coal justifies a premium price. Moreover, underground mining of thinner coalbeds in the eastern U.S. is also possible because these Carboniferous-age coalbeds typically show uniform thickness over large areas, which allows sufficient production to recover the cost of thin-coal mining equipment. Cretaceous-age coalbeds in Utah show more thickness variation. Because Utah coal is sold primarily to local power plants, rather than to more lucrative markets, it seems unlikely that thin Utah coalbeds can be economically mined. Furthermore, even if a premium price is offered for Utah coal, mining these thinner coalbeds will be challenging because they are not uniformly thick over large areas. Given these circumstances, we used a 4-ft minimum thickness to identify the underground-minable coal resource.

Table 5. *Restrictions to mining in the Alton coalfield, Kane County, Utah (modified from Rohrbacher and others, 1993).*

Land-use restrictions[1]	Buffer or Factor
Highways	100 ft on either side
Perennial streams	100 ft on either side
Lakes or reservoirs	100 ft around margin
Towns or residences	300-ft radius
National Park or Monument	100 ft around margin

Technical restrictions	Buffer or Factor
Minimum bed thickness	1 ft (surface-minable coal) 4 ft (underground-minable coal)
Minimum overburden	200 ft (underground-minable coal) 20 ft (surface-minable coal)
Maximum bed thickness	14 ft (underground-minable coal)
Maximum overburden	200 ft (surface-minable coal) 3000 ft (underground-minable coal)
Minimum interburden	40 ft (underground-minable coal)
Faults	50 ft on either side (underground-minable coal)
Barrier for abandoned mines (included with mined-out coal)	50 ft around margin

[1] No railroads, radio towers, power lines, or pipelines are present in the coal-bearing parts of the study area.

Although coalbeds greater than 14 ft thick are actively mined in Utah, current underground mining methods can recover only a maximum 14-ft-thick segment of the coalbed; the remaining coal is lost in the gob pile behind the longwall mining machine. Accordingly, we used a maximum 14-ft thickness restriction to identify the underground-minable coal resource.

Other technological restrictions to underground mining were also considered. To avoid unstable roof conditions and possible water infusions, most mines leave a 50-ft barrier near faults. Burned or oxidized coal behind the outcrop commonly causes operators to leave coal near the outcrop. Weathering near the outcrop sometimes extends to several hundred feet of burial. We chose a minimum 20-ft burial depth restriction to exclude weathered coal. In areas having multiple coalbeds, 40 ft of interburden is required to allow for stable roof and floor conditions if both of the coalbeds are mined. Since the two beds in the study area are nowhere closer than the 40-ft interburden restriction, this restriction does not apply to coal in the Alton field.

The maximum amount of overburden routinely planned for at most Utah coal mines is 2500 ft. However, some operators are considering mining to depths of 3000 ft, so a 3000-ft maximum burial depth restriction was used in this study. Regulations require coal operators to leave a 50-ft barrier between abandoned and active coal mine workings to avoid potential ventilation or water infusion problems. Accordingly, we applied a 50-ft buffer restriction to the perimeter of abandoned coal mines.

Land-use restrictions for underground mining are intended to protect surface features from damage that might result from surface subsidence above underground mines. Protected surface features in the study area include highways, perennial streams, lakes, reservoirs, buildings, municipalities, and National Parks and Monuments. Land-use restrictions that prohibit mining under railroads, radio towers, power lines, producing oil and gas wells, and pipelines were not considered because these features do not occur in the study area.

Restrictions for Surface-Minable Coal

Examination of the coalbed depth maps for the Alton coalfield shows areas with surface-minable coal. The steep topography of most of Utah's coalfields has generally precluded surface coal mines in Utah. Consequently, restrictions appropriate to surface mines in Utah are not well established. Nonetheless, restrictions to surface mining listed in table 5 were applied. Note that a 200-ft maximum overburden depth was used to delineate areas haviing surface-minable coal. The 20-ft minimum overburden restriction excludes coal near the outcrop, where the coal is often burned or oxidized. Because thin coal is more easily recovered by surface-mining than it is by underground-mining, a one-ft minimum coalbed thickness restriction was used to identify surface-minable coal.

Thickness Categories

Coalbed thickness categories used in this study are similar to those recommended by the USGS (Wood and others, 1983). We deviated slightly from the USGS classification to account for current Utah mining practice, which preferentially selects coalbeds that are more than 6 ft thick. Table 6 compares the coalbed thickness categories used in this report to those recommended by the USGS.

Table 6. *Coalbed thickness categories used in this report compared to those used in the Coal Resource Classification System of the USGS. (Wood and others, 1983).*

This Report		USGS	
Feet	**Inches**	**Feet**	**Inches**
1 to 2	12 to 24	1.2 to 2.3	14 to 28
2 to 4	24 to 48	2.3 to 3.5	28 to 42
4 to 6	48 to 72	3.5 to 7.0	42 to 84
6 to 10	72 to 120	7 to 14	84 to 168
10 to 14	120 to 168		
+ 14	+ 168	+ 14	+ 168

Overburden Categories

Table 7 compares the overburden categories used in this report to those recommended by the USGS (Wood and others, 1983). To identify shallow coal that is probably weathered or burned we used a 0- to 20-ft restriction for surface-minable coal; coal from 20 to 200 ft of overburden was used as the category for surface-minable coal, and coal deeper than 200 ft was considered underground minable. Our definition of surface-minable coal is more restrictive than the USGS-recommended 0- to 500-ft-overburden category to identify coal that can be mined by open-pit methods. For underground-minable coal deeper than 1000 ft, we used equal 1000-ft intervals down to 3000 ft, and then lumped all coal deeper than 3000 ft together.

Reliability Categories

Three reliability categories (Wood and others, 1983) were used in this study:

(1) the "demonstrated coal resource" must be within 0.75 mile of a measured thickness location,

(2) the "inferred coal resource" is between 0.75 and 3 miles of a measured thickness location, and

(3) the "hypothetical coal resource" is more than 3 miles from a measured thickness location.

RESOURCE CALCULATION RESULTS

The Original Coal Resource

The original coal resource is the amount of minable coal that existed in the study area before mining, and without consideration of land-use or technical restrictions. Two factors are important when considering the original coal resource. The thickness of the individual coalbeds has obvious significance; coal in thin beds has little economic potential whereas coal in thick beds is potentially minable. The depth of the original coal resource is also important. Deeply buried coalbeds have little economic significance whereas coal at shallow to modest depths is more economically attractive.

Thickness of the Original Coal Resource

Table 8 shows tonnage values according to thickness categories for the two coalbeds in the Alton coalfield. The total original coal resource is estimated to be 5.51 billion tons. Twelve percent (672 million tons) of the original resource is surface minable and 88% (4.84 billion tons) is underground minable. About 80% (4.41 billion tons) of the underground-minable coal is in beds greater than 4 ft thick; most of this thicker coal is in the Smirl bed.

Depth of the Burial of the Original Coal Resource

Table 9 shows the distribution of the original coal resource by burial depth for the Smirl and Bald Knoll coalbeds. About 3.63 billion tons (66%) of this coal is at depths suitable for underground mining (between 200 and 3000 ft deep). Roughly two-thirds (2.39 billion tons) of this underground-minable resource is contained in the Smirl bed.

Calculation of the Available Coal Resource

The available coal resource includes that part of the original coal resource that remains after subtraction of coal in areas affected by past mining and subtraction of coal that cannot be mined due to technical or land-use restrictions. Table 10 shows the effect of technical and land-use restrictions on the available coal resource. Note that the available coal tonnage is greater than the value obtained by sequentially subtracting the individual tonnage restrictions. This is because coal in areas subject to more than one restriction is only subtracted once.

Coal Lost to Technical Restrictions

About 7% (360 million tons) of the original coal resource is in beds that are too thin for underground mining (less than 4 ft thick). About 25% (1.21 billion tons) is in beds that are too deep to mine. About 2% (93 million tons) is too thick to be fully mined by current underground technology. Other technical restrictions (table 10) are less significant.

Coal Lost to Land-Use Restrictions

Land-use restrictions in total exclude 515 million tons of coal, which is about 11% of the original coal resource in the study area. About 49 million tons is lost because of rules that prohibit mining under lakes and perennial streams, 24 million tons is lost where the coal is under improved roads, and 284 million tons underlie Bryce Canyon National Park and Grand Staircase-Escalante

Table 7. *Overburden categories used in this report compared to those used in the Coal Resource Classification System of the USGS (Wood and others, 1983).*

This Report (ft)	**USGS (ft)**
0 to 200[1]	0 to 500
200 to 1000	500 to 1000
1000 to 2000	1000 to 2000
2000 to 3000	2000 to 3000
3000 to 6000	3000 to 6000

[1] A zero to 20-ft restriction is applied to this category to calculate the surface-minable fraction of the available coal resource, whereas all of this coal is excluded from the underground-minable, available coal resource.

Table 8. *Original coal resource tonnage in the Smirl (SM) and Bald Knoll (BK) coalbeds by coalbed thickness and mining method, Alton coalfield, Kane County, Utah (million tons).*

Coalbed	**COALBED THICKNESS** (ft)								**TOTAL**			
mining method	1-2	2-4	4-6	6-8	8-10	10-12	12-14	+ 14	surface	under-ground	sum	%
SM												
surface	0	2	4	8	20	45	69	294	443	—	3715	67
underground	-	1	28	53	170	711	768	1542	—	3272		
BK												
surface	2	25	11	15	79	27	39	16	229	—	1793	33
underground	3	423	342	174	195	103	314	25	—	1564		
TOTAL	5	451	385	250	464	886	1190	1877	672	4836	5508	100
PERCENT	>1	8	7	5	8	16	22	34	12	88		

TOTAL values may differ from results obtained by summing rows or columns due to rounding.
Zeros indicate rounded values less than 0.5 million ton.
Dashes (—) indicate null (true zero) values.

Table 9. *Original coal resource tonnage in the Smirl (SM) and Bald Knoll (BK) coalbeds by burial depth, Alton coalfield, Kane County, Utah (million tons).*

	DEPTH (ft)					**TOTAL**	**TOTAL**	**PERCENT**
COALBED	0 to 200	200 to 1000	1000 to 2000	2000 to 3000	3000 to 6000	All depths	200 to 3000 ft deep	200 to 3000 ft deep
SM	443	828	729	832	882	3715	2389	66
BK	229	483	296	460	325	1793	1239	34
TOTAL	672	1311	1025	1292	1207	5508	3628	
PERCENT	12	24	19	23	22	100	66	

TOTAL values may differ from results obtained by summing rows or columns due to rounding.

Table 10. Coal tonnage lost to technical and land-use restrictions, and tabulation of the net available coal resource for the Smirl (SM) and Bald Knoll (BK) coalbeds in the Alton coalfield, Kane County, Utah (million tons).

ORIGINAL MINABLE COAL RESOURCE			TECHNICAL RESTRICTIONS						LAND-USE RESTRICTIONS					AVAILABLE COAL RESOURCE		
COAL BED	Surface	Underground	Thin	Shallow	Deep	Mined	Faulted	Thick	Bryce Canyon N.P.	GSENM*	Water	Roads	Towns	Surface	Underground	TOTAL
SM	439	2660	15	63	844	0	15	92	57	121	31	16	69	328	1548	1876
BK	226	1553	345	15	323	0	10	0	44	62	18	8	89	175	864	1039
TOTAL	665	4213	360	78	1206	0	25	93	101	183	49	24	158	503	2411	2914
PERCENT	14	86	7	2	25	0	0	2	2	4	1	0	3	10	49	60

ORIGINAL COAL RESOURCE

Surface is surface-minable coal in beds more than 1 ft thick where the overburden is between 20 and 200 ft and a block size of more than 10 acres.

Underground is underground-minable coal in beds more than 1 ft thick, (generally excluding riders, splits, and sub-beds) that do not occur in areas designated as surface-minable.

RESTRICTIONS are individually tabulated for:

Thin	underground-minable coal in beds less than 4 ft thick
Shallow	underground-minable coal less than 200 ft deep
Deep	underground-minable coal more than 3,000 ft deep
Mined	coal previous mined, or undermined (including a 50-ft buffer)
Faulted	underground-minable coal within 50 ft of a fault
Thick	underground-minable coal in parts of a bed that is more than 14 ft thick
Bryce Canyon N.P.	underground-minable coal that underlies the park
*GSENM**	underground-minable coal that underlies the monument
Water	coal under a perennial stream or water body (100-ft buffer)
Roads	coal under an improved road (100-ft buffer)
Towns	coal under buildings or municipalities (300-ft buffer)

AVAILABLE COAL RESOURCE is the net total coal remaining after subtraction of restricted coal; coal in areas subject to multiple restrictions is only subtracted once.

TOTAL values may differ from results obtained by summing columns due to rounding.

PERCENT is percentage of original minable coal tonnage (*Surface* + *Underground* = 4878 million tons).

ZEROS indicate rounded values less than 0.5 million tons.

***GSENM** = Grand Staircase-Escalante National Monument

National Monument (GSENM). The direct effect of the land-use restriction where coal under towns is prohibited from mining removes another 158 million tons of coal (attributable to coalbeds under the towns of Alton, Orderville, and Glendale).

THE AVAILABLE COAL RESOURCE

Table 10 shows that the Smirl coalbed accounts for over 64% of the 2.91-billion-ton available coal resource in the Alton coalfield. Eighty-three percent (2.41 billion tons) of the coal is underground-minable, and 17% (503 million tons) is surface-minable.

The 2.91-billion-ton available coal resource that we calculated for the Alton coalfield (table 10) is an estimate. In the following sections we use two approaches to evaluate the reliability of this estimate. First, we consider the spatial distribution of drill-hole observations used to calculate the available coal resource. Second, we compare the results from this study with results from a previous study.

The reliability of the available coal resource estimate is evaluated using a classification from Wood and others (1983). About 30% (871 million tons) of the available coal resource identified in this report is demonstrated (less than 0.75 miles from a thickness location), 54% (1.66 billion tons) is inferred (0.75 to 3 miles from a thickness location), and about 16% (455 million tons) is hypothetical (more than 3 miles from a thickness location). Table 11 shows the reliability of the available coal resource by coalbed.

Table 12 compares the available coal resource estimate from this study to a similar estimate reported by Doelling (1972). Doelling's resource estimate is for coalbeds that are more than 4 ft thick, and less than 3000 ft deep. Although we also tabulate the coal resource for coalbeds that are more than 4 ft thick and less than 3000 ft deep, the comparison shown in table 12 is approximate rather than exact. Furthermore, our available coal resource estimate excludes restricted coal (table 10) whereas Doelling's estimate includes this coal. Finally, different reliability categories are used in the two studies. To provide a more equitable comparison, the sum of the demonstrated and the inferred coal resource shown in table 11 is listed as the identified coal resource in table 12. Doelling's Class I, II, and III coal resource estimates are similarly combined and listed in table 12, and his Class IV coal resource estimate is directly compared to our hypothetical coal resource estimate.

We estimate about twice as much coal in the Alton coalfield than reported in Doelling's (1972) monograph (table 12). Given the significantly greater amount of drill-hole data available in this study, a doubling of the coal resource is not remarkable. Interestingly, the percentage of coal in each reliability category remained about the same. Doelling (1972) found that 15% of the coal is a Class IV resource ("potential coal … based on geographic and geologic position with little supporting data") whereas our study shows that 16% of the coal is not reliably known (hypothetical coal, more than 3 miles from a thickness observation) (table 11).

DISCUSSION

The significance of the 2.91-billion-ton available coal resource estimate depends on how much of this coal is produced in the near future. Predicting future production is clearly less certain than estimating the available coal resource. Nonetheless, we estimate the coal production potential of the Alton coalfield by considering the thickness and distribution of the available coal resource, as well as local mining practices.

Table 13 shows that about 16% (383 million tons) of the underground-minable, available coal resource is in coalbeds that are less than 6 ft thick. Such relatively thin coal is rarely mined in Utah. About 2.03 billion tons of the available coal resource is in beds that are more than 6 ft thick. However, about 75 million tons (4%) of this thick coal occurs under the GSENM or Bryce Canyon National Park. Also, some surface-minable coal within view of Bryce Canyon may not be mined in order to protect the park's view shed.

Underground coal mines in central Utah's Wasatch Plateau coalfield typically recover about 35% of the available coal resource (Rohrbacher and others, 2001). Recovery from the Alton coalfield could likewise be about 35% because there are only two minable coalbeds, but they are subject to more land-use restrictions than those in the Wasatch Plateau (Doelling 1972). Table 3 shows that the disturbed coal has accounted for less than 70,000 tons of production. We estimate that past mining recovered less than 25% of the in-place resource (approximately 335,000 tons); this relatively low recovery is partly due to the fact that mining removed only about half of the exceptionally thick coalbed's height. Past mining in the Alton coalfield was also by less-efficient room and pillar methods, while future mining will likely utilize more-efficient surface or longwall mining methods. Thus, an estimated future coal mining recovery rate of 35% for the Alton coalfield, similar to that of the other central Utah coalfields, is not unreasonable if more efficient surface- or longwall-mining methods are employed. More efficient mining should also tend to offset the greater amount of land-use restrictions.

Excluding the minable coal within Bryce Canyon National Park and GSENM, and assuming a 35% recovery from underground mines and 80% recovery from the remaining surface-minable coal, we anticipate that up to 1.25 billion tons of coal may be produced from the Alton coalfield. Two caveats bear on this estimate. First, still more coal could be produced if higher coal prices or technological advances enable economic mining of thinner coal and increase the recovery factor. Second, less coal may be produced if the somewhat high sulfur and mercury content of coals in the Alton coalfield limit their marketability, or if mining is restricted due to changing environmental regulations.

SUMMARY

Maps showing the thickness and distribution of the available coal resource for two coalbeds in the Alton coalfield are provided in the appendix. Of the 5.51 billion ton original coal resource, only 2.91 billion tons is part of the available coal resource. About 1.57 billion tons of the original coal resource is in coalbeds that are too thin (less than 4 ft thick) or too deep (more than 3000 ft) for mining. Smaller amounts of coal (78 million tons) are near surface and presumably weathered or burned. Past mining has dis-

Table 11. *The available coal resource tonnage for the Smirl (SM) and Bald Knoll (BK) coalbeds by reliability category, Alton coalfield, Kane County, Utah (million tons).*

	Reliability Category			
COALBED	**Demonstrated**	**Inferred**	**Hypothetical**	**TOTAL**
SM	667	926	282	1876
BK	204	662	173	1039
TOTALS	871	1588	455	2914

Reliability Category(*s*) from Wood and others (1983).

Demonstrated is coal within 0.75 mile of an observation location.

Inferred is coal between 0.75 and 3 miles of an observation location.

Hypothetical is coal more than 3 miles from an observation location.

TOTAL values may differ from results obtained by summing rows or columns due to rounding.

Table 12. *Coal resource tonnage and reliability estimates from an earlier study compared to results from this study, Alton coalfield, Kane County, Utah (million tons).*

	Identified & Inferred[1]	**Hypothetical**	**Total**
Doelling (1972)	1176	209	1386
This study[2]	2459	455	2914

[1] Identified & inferred equated to Doelling’s Class I, II, and III resource categories; hypothetical equated to Doelling’s Class IV

[2] the available coal resource

Table 13. *The underground-minable, available coal resource for the Smirl (SM) and Bald Knoll (BK) coalbeds by coalbed thickness, Alton coalfield, Kane County, Utah (million tons).*

	COALBED THICKNESS (ft)								**TOTAL**	
COALBED	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	4+ ft	6+ ft
SM	143	238	259	203	308	298	93	4	1548	1405
BK	240	191	147	75	205	6	—	—	864	624
TOTAL	383	429	406	278	513	304	94	5	2411	2029

TOTAL values may differ from results obtained by summing rows or columns due to rounding.
Dashes (—) indicate null (true zero) values.

turbed very little of the original coal resource (approximately 335,000 tons), while 515 million tons is subject to land-use restrictions. Other findings include:

- Only 30% of the available coal resource identified in this study is demonstrated (within 0.75 miles of a measurement location).
- Over 64% of the available coal resource is in the Smirl coalbed.
- Coal rank is subbituminous A.
- Average sulfur content is 1 pound of sulfur per million Btu for the Bald knoll coalbed, and 1.3 pounds of sulfur per million Btu for the Smirl coalbed.
- As-received basis ash values are typically near 11% for the Smirl coalbed, and 23% for the Bald Knoll coalbed.
- Available data show that the in-ground coal in the study area averages 13 pounds mercury per trillion Btu (lbs $Hg/10^{12}$ Btu), which is three times higher than the average mercury content of coal in the nearby Wasatch Plateau and Book Cliffs coalfields, but about the same as the U.S. average of 13 lbs $Hg/10^{12}$ Btu.

Nearly 16% (383 million tons) of the underground-minable, available coal resource occurs in beds that are less than 6 ft thick. Because Utah's underground coal mines rarely produce from beds that are less than 6 ft thick, this coal is unlikely to be mined soon. Furthermore, about 284 million tons of the minable coal lie within Bryce Canyon National Park and the GSENM; this coal is also unlikely to be mined. Excluding the coal within Bryce Canyon, GSENM, and the relatively thin 4- to 6-ft-thick coal, and assuming 35% recovery from underground mines and 80% recovery from surface mines, about 1.25 billion tons of coal may still be produced from the Alton coalfield. This potential production is sufficient to satisfy Utah's current coal consumption (18 million tons per year) for about 70 years.

ACKNOWLEDGMENTS

We acknowledge funding for this project from the U.S. Geological Survey, Department of the Interior under cooperative agreement number 05ERAG0008. We also thank Susan J. Tewalt of the U.S. Geological Survey, Doug Powell of the Kanab field office of the U.S. Bureau of Land Management, and Robert Ressetar and Kimm Harty of the Utah Geological Survey for their helpful reviews of a draft version of the report. The Utah Division of Oil, Gas and Mining provided data on the location of oil and gas wells in the study area. Finally, the Utah Automated Geographic Reference Center provided digital elevation models, as well as digital land grid, topographic, road, and stream coverages for the study area.

REFERENCES

Affolter, R.H., and Hatch, J.R., 1980, Chemical analyses of coal from the Dakota and Straight Cliffs Formations, Southwestern Utah Region, Kane and Garfield Counties, Utah: U.S. Geological Survey Open-File Report 80-138, 32 p.

American Society for Testing and Materials (ASTM), 1990, D 388-90, Standard classification of coals by rank: West Conshohocken, Pennsylvania, v. 05.05, p. 193-196.

Bragg, L.J., Oman, J.K., Tewalt, S.J., Oman, C.L., Rega, N.H., Washington, P.M., and Finkelman, R.B., 1997, U.S. Geological Survey coal quality (COALQUAL) database- version 2.0: U.S. Geological Survey Open-File Report 97-134, CD-ROM.

Bowers, W.E., 1977, Geophysical logs of twelve test holes drilled in 1976, in the Alton-Kanab coal field, Garfield and Kane Counties, Utah: U.S. Geological Survey Open-File Report 77-43, 5 p.

Bowers, W.E., Aigen, A.A., and Landis, E.R., 1976, Coal resources of the Alton, Utah, EMRIA site: U.S. Geological Survey Open-File Report 76-386, 32 p., 1 plate, scale 1:24,000.

Cashion, W.B., 1961, Geology and fuel resources of the Orderville-Glendale area, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C-49, 1 plate, scale 1:62,500.

Cohenour, R.E., 1963, Coal resources of part of the Alton area, Kane County, Utah: Utah Geological and Mineralogical Survey Report of Investigation No. 2, 20 p., 3 page-sized maps.

Doelling, H.H., 1968, Carcass Canyon coal area, Kaiparowits Plateau, Garfield and Kane Counties, Utah: Utah Geological and Mineralogical Survey Special Studies 25, 23 p.

—1972, Alton coal field, *in* Doelling, H.H., and Graham, R.L., Southwestern Utah coal fields – Alton, Kaiparowits Plateau, and Kolob-Harmony: Utah Geological and Mineralogical Survey Monograph Series no. 1, p. 1-65.

Doelling, H.H., Smith, A.D., and Davis, F.D., 1979, Methane content of Utah coals, *in* Smith, M., editor, Coal studies: Utah Geological and Mineral Survey Special Studies 49, p. 1-60.

Eggleston, J.R., Carter, M.D., and Cobb, J.C., 1990, Coal resources available for development – a methodology and pilot study: U.S. Geological Survey Circular 1055, 15 p.

Gregory, H.E., 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geological Survey Professional Paper 226, 116 p.

Grose, L.T., Hileman, D.H., and Ward, A.E., 1967, Coal resources of southwestern Utah – potential for utilization in steam-electric power-generation plants: U.S. Bureau of Mines Information Circular 8326, 78 p.

Gustason, E.R., 1989, Stratigraphy and sedimentology of the middle Cretaceous (Albian-Cenomanian) Dakota Formation, southwestern Utah: Boulder, University of Colorado, Ph.D. dissertation, 376 p.

Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital geologic map of Utah: Utah Geological Survey Map 179DM, CD-ROM.

Hower, J.C., Griswold, T.B., and Pollock, J.D., 1989, Caveats on the use of published coal quality data: Journal of Coal Quality, v. 8, p. 49-51.

Hucka, B.P., Sommer, S.N., and Tabet, D.E., 1997, Petrographic and physical characteristics of Utah coals: Utah Geological Survey Circular 94, 80 p.

Hylland, M.D., and Lund, W.R., 2003, Guide for the preparation of reports for the Utah Geological Survey, second edition: Utah Geological Survey Miscellaneous Publication 03-7, 68 p.

Institute of Electrical and Electronics Engineers (IEEE), 1997, Standard for the use of the International System of Units (SI) – The modern metric system: New York, New York, IEEE Inc. and West Conshohocken, Pennsylvania, American Society for Testing and Materials, IEEE/ASTM SI 10-1997, 66 p.

Kirschbaum, M.A., and McCabe, P.J., 1992, Controls on the accumulation of coal and on the development of anastomosed fluvial systems in the Cretaceous Dakota Formation of southern Utah: Sedimentology, v. 39, p. 581-598.

Kohler, J.F., Quick, J.C., and Tabet, D.E., 1997, Variation in the chemistry of Upper Cretaceous, Straight Cliffs Formation coals, *in* Hill, L.M., editor, Learning from the land: Grand Staircase-Escalante National Monument Science Symposium Proceedings, Cedar City, Utah: Utah, U.S. Department of Interior, Bureau of Land Management, BLM/UT/GI-98/006+1200, p. 307-318.

Lamarre, R.A., 2003, Hydrodynamic and stratigraphic controls for a large coalbed methane accumulation in Ferron coals of east-central Utah: International Journal of Coal Geology, v. 56, p. 97-110.

Lawrence, J.C., 1965, Stratigraphy of the Dakota and Tropic Formations of Cretaceous age in southern Utah, *in* Goode, H.D., and Robison, R.A., editors, Geology and resources of south-central Utah: Utah Geological Society and Intermountain Association of Petroleum Geologists Guidebook 19, p. 71-91.

Quick, J.C., Brill, T.C., and Tabet, D.E., 2003, Mercury in US coal – observations using the COALQUAL and ICR data sets: Environmental Geology, v. 43, p. 247-259.

Richardson, G.B., 1909, The Harmony, Kolob, and Kanab coal fields, southern Utah: U.S. Geological Survey Bulletin 341-C, p. 379-400.

Robison, R.A., 1963a, A reconnaissance survey of the coal resources of southwestern Utah: Utah Geological and Mineralogical Survey Special Studies No. 3, 34 p.

Robison, R.A., 1963b, Coal resources of southwestern Utah, *in* Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah – transition between Basin-Range and Colorado Plateau Provinces: Intermountain Association of Petroleum Geologists 12th Annual Field Conference, p. 151-156.

Robison, R.A., 1964, Progress report on the coal resources of southern Utah -1963: Utah Geological and Mineralogical Survey Special Studies No. 7, 28 p.

Rohrbacher, T.J., Teeters, D.D., Sullivan, G.L., and Osmonson, L.M., 1993, Coal resource recoverability, a methodology: U.S. Bureau of Mines Information Circular 9368, 48 p.

Rohrbacher, T.J., Molnia, C.L., Osmonson, L.M., Carter, M.D., Eakins, W., Hoffman, G.K., Tabet, D.E., Schultz, J.E., Scott, D.C., Teeters, D.D., Jones, G.E., Quick, J.C., Hucka, B.P., and Hanson, J.A., 2001, Chapter F, coal availability, recoverability, and economic evaluations of coal resources in the Colorado Plateau, Colorado, New Mexico, and Utah, *in* Kirschbaum, M.A., Roberts, L.N.R., and Biewick, L.R.H, editors, Geologic assessment of coal in the Colorado Plateau – Arizona, Colorado, New Mexico, and Utah: U.S. Geological Survey Professional Paper 1625–B, Online, <energy.cr.usgs.gov/coal/coalar/index.htm>, accessed March 2004.

Ulicny, D., 1999, Sequence stratigraphy of the Dakota Formation (Cenomanian), southern Utah – interplay of eustasy and tectonics in a foreland basin: Sedimentology, v. 46, p. 807-836.

U.S. Environmental Protection Agency (EPA), 2005, Standards of performance for new and existing stationary sources – Electric utility steam generating units: U.S. Federal Register, v. 70, p. 28606-28700.

Utah Automated Geographic Reference Center (UAGRC), 2005, Utah's statewide geographic information database: Online, <agrc.utah.gov/agrc_sgid/sgidintro.html>, accessed 2005.

Utah Division of Oil, Gas and Mining, 2005, Utah oil and gas information center: Online, <ogm.utah.gov/oilgas/default.htm>, accessed June 2005.

Utah Geological and Mineral Survey (UGMS), 1983, Energy resources map of Utah, scale 1:500,000.

Vanden Berg, M.D., 2005, Annual review and forecast of Utah coal production and distribution, 2004: Online, <geology.utah.gov/online/ofr/ofr-463.pdf>, accessed March 2006.

Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culberston, W.C., 1983, Coal Resource Classification System of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

APPENDIX

TABULATIONS OF THE AVAILABLE COAL RESOURCE AND ASSOCIATED MAPS, FOR TWO COALBEDS IN THE ALTON COALFIELD, KANE COUNTY, UTAH

Notes to tables:

The **coalbed thickness** includes rock partings less than 1 ft thick.

The **surface-minable, original coal resource** includes coal in beds more than 1 ft thick, where the coal is more than 20 ft deep and less than 200 ft deep, The surface-minable coal includes coal in associated riders, splits, and subbeds.

The **underground-minable, original coal resource** includes coal in areas without surface-minable coal, and generally excludes coal in associated riders, splits, and sub-beds.

Restricted coal cannot be mined due to land-use or technical restrictions. **Land-use restrictions** exclude coal under roads, towns, National Parks and Monuments, and water bodies. **Technical restrictions** exclude coal near mined-out areas and faults, coal less than 4 ft thick, coal exceeding the 14-ft thick underground minable maximum, and coal more than 3000 ft deep. A 200-ft minimum depth is applied to underground-minable coal to exclude surface-minable coal; for surface-minable coal, a 20-ft minimum depth is applied to exclude weathered or burned coal. The **net restricted coal** shows the total amount of restricted coal where coal in areas subject to multiple restrictions is only counted once.

The **available coal resource** is that part of the original coal resource that is not restricted. Three **reliability categories** (Wood and others, 1983) are recognized: **Demonstrated**, includes the available coal resource within 0.75 miles of a measured thickness location, **Inferred**, includes the available coal resource between 0.75 and 3 miles of a measured thickness location, and **Hypothetical**, includes the available coal resource more than 3 miles from a measured thickness location.

Reporting conventions used in the tables include:

Numeric values show million tons coal, rounded to the nearest whole value.

Coal in beds less than 4 ft thick is not included in sums of the underground-minable available coal resource.

Zeros indicate rounded values less than 0.5 million tons.

Dashes (–) indicate null (true zero) values.

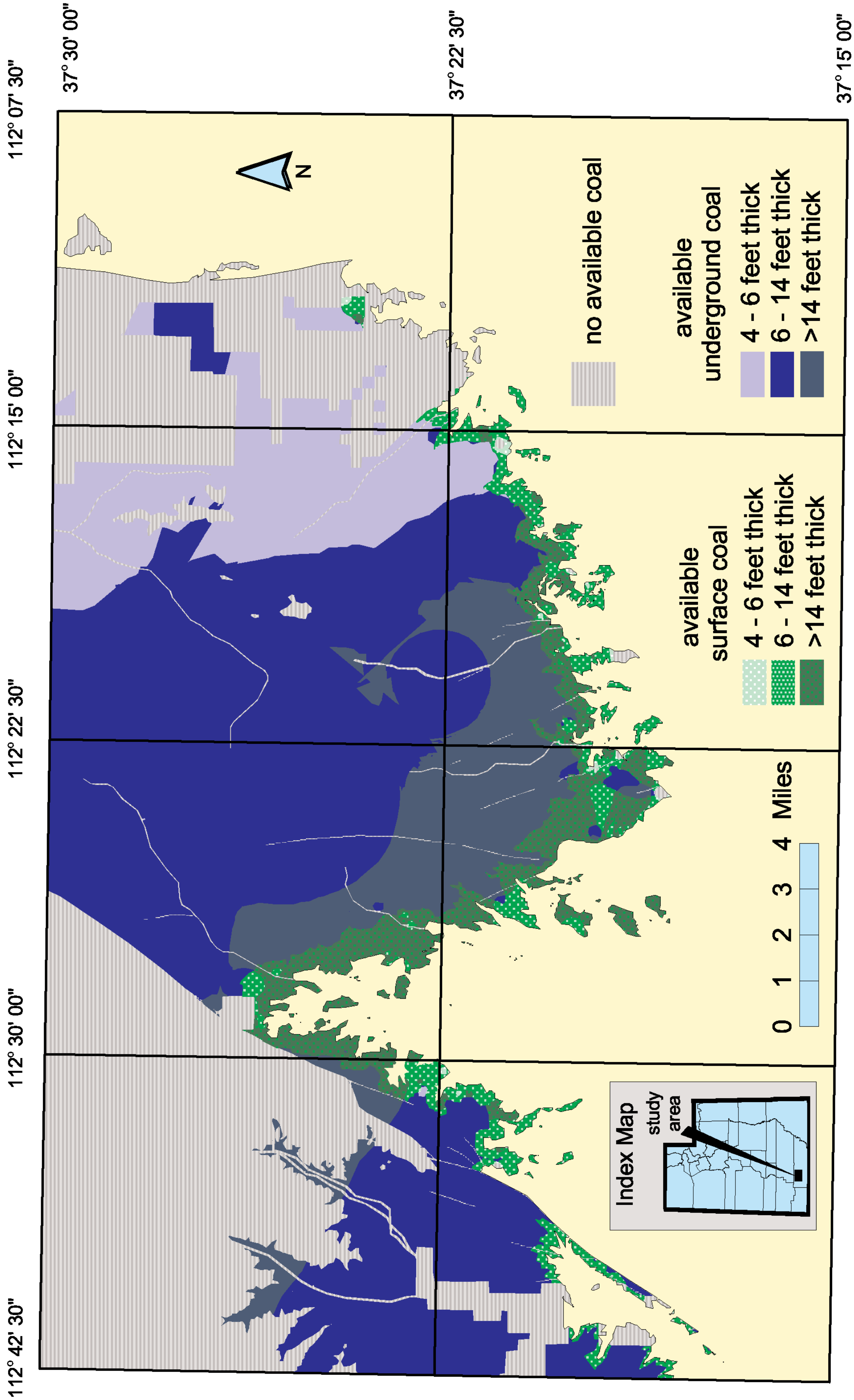

Figure A1. *Location of the available coal resource for the Smirl coalbed, Alton coalfield.*

Table A1. *Tabulation of the available coal resource for the Smirl coalbed by coalbed thickness, Alton and part of the Kolob coalfields, Kane County, Utah (million tons).*

Coalbed thickness (ft)	Original Minable Coal	Restrictions										Net Restricted Coal	Reliability						Available Coal		
													surface coal			underground coal					
		fault	water	roads	towns	National Park	National Monument	too thick	too thin	too shallow	too deep		demonstrated	inferred	hypothetical	demonstrated	inferred	hypothetical	surface	underground	Total
1-2	0	—	—	—	—	0	—	—	0	0	—	0	—	—	—	—	—	—	—	—	—
2-4	17	0	0	—	—	2	7	—	14	0	—	16	1	—	—	—	—	—	1	—	1
4-6	250	0	3	1	—	44	54	—	—	1	6	105	2	—	—	22	55	67	2	143	145
6-8	270	0	2	—	—	10	12	—	—	1	1	26	5	—	—	48	128	62	5	238	243
8-10	306	3	2	0	1	0	7	—	—	5	15	32	10	4	—	45	154	60	14	259	273
10-12	303	1	2	0	11	—	8	—	—	6	42	70	21	6	3	11	147	45	31	203	234
12-14	640	1	6	6	48	—	12	—	—	9	210	282	46	3	—	59	225	25	50	308	358
14-16	975	6	12	7	7	—	8	63	—	18	499	563	109	5	—	104	177	17	114	298	413
16-18	314	2	3	1	1	—	14	28	—	20	70	124	92	5	—	75	15	3	97	93	190
18-20	23	0	1	—	—	—	0	1	—	2	—	4	15	—	—	4	—	—	15	4	19
sum	3,099	15	31	16	69	57	121	92	15	63	844	1,223	300	24	3	367	902	279	328	1,548	1,876

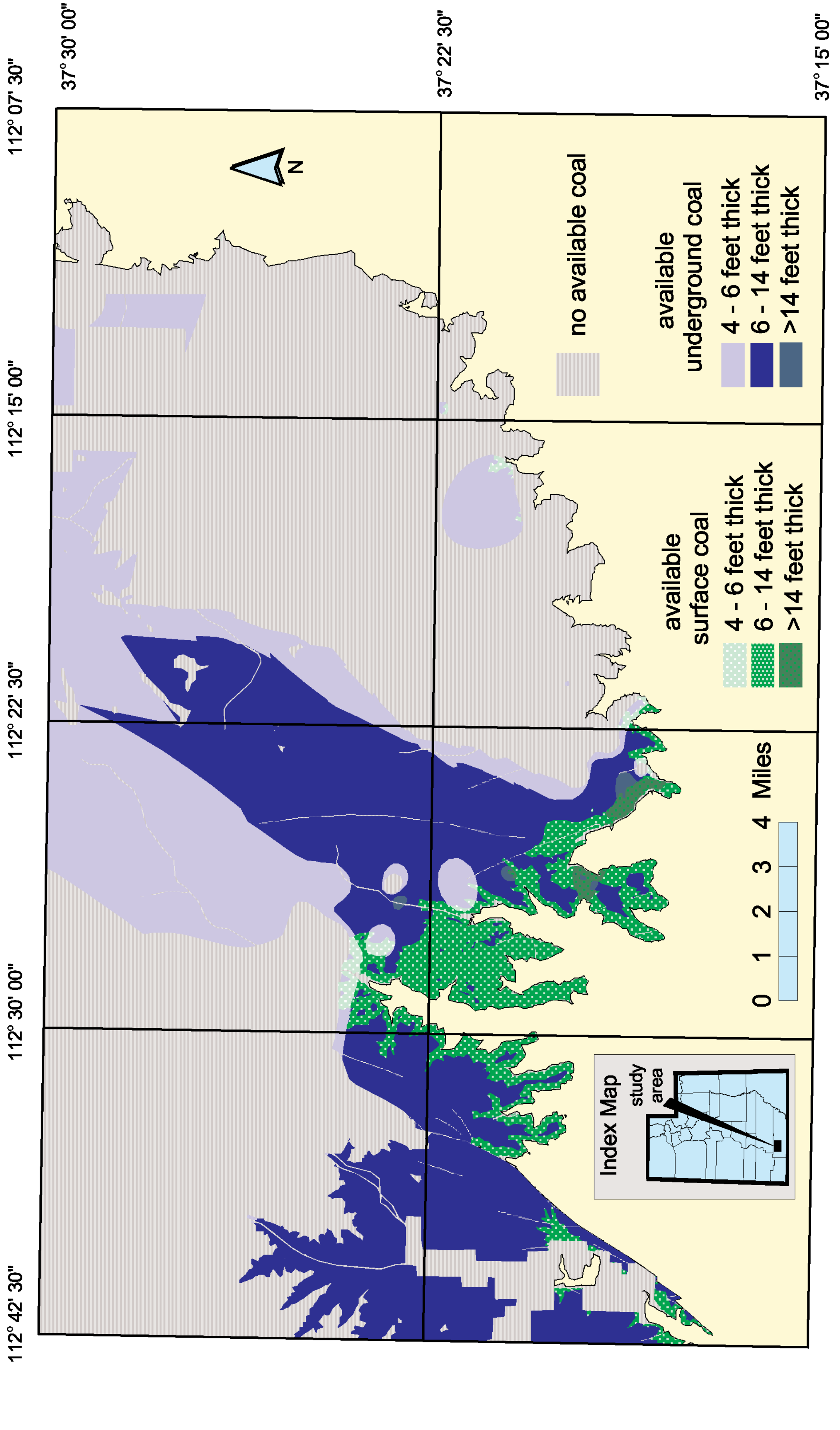

Figure A2. *Location of the available coal resource for the Bald Knoll coalbed, Alton coalfield.*

Table A2. Tabulation of the available coal resource for the Bald Knoll coalbed by coalbed thickness, Alton and part of the Kolob coalfields, Kane County, Utah (million tons).

	Original Minable Coal	Restrictions										Net Restricted Coal	Reliability						Available Coal		
													surface coal			underground coal					
Coalbed thickness (ft)		fault	water	roads	towns	National Park	National Monument	too thick	too thin	too shallow	too deep		demonstrated	inferred	hypothetical	demonstrated	inferred	hypothetical	surface	underground	Total
1-2	6	0	0	—	—	—	4	—	6	0	0	6	—	—	—	—	—	—	—	—	0
2-4	367	1	4	2	2	11	38	—	342	1	97	349	7	4	—	—	—	—	11	—	19
4-6	421	1	5	2	—	33	16	—	—	1	128	174	5	5	—	41	142	57	9	240	246
6-8	261	1	2	0	—	—	1	—	—	2	51	56	8	3	—	19	119	52	11	191	205
8-10	265	2	1	0	—	—	3	—	—	4	30	40	5	26	—	35	97	14	31	147	224
10-12	118	1	1	0	—	—	—	—	—	2	11	16	21	44	9	19	39	17	74	75	102
12-14	320	3	6	4	88	—	—	—	—	4	5	98	3	6	7	20	168	17	16	205	222
14-16	15	0	0	—	—	—	—	0	—	1	—	2	6	7	0	6	—	—	14	6	14
16-18	5	—	—	—	—	—	—	0	—	0	—	0	5	—	—	—	—	—	5	—	5
18-20	1	—	—	—	—	—	—	0	—	0	—	0	4	—	—	—	—	—	4	—	1
sum	1,779	10	18	8	89	44	62	0	349	15	323	740	63	95	16	141	566	157	175	864	1,039

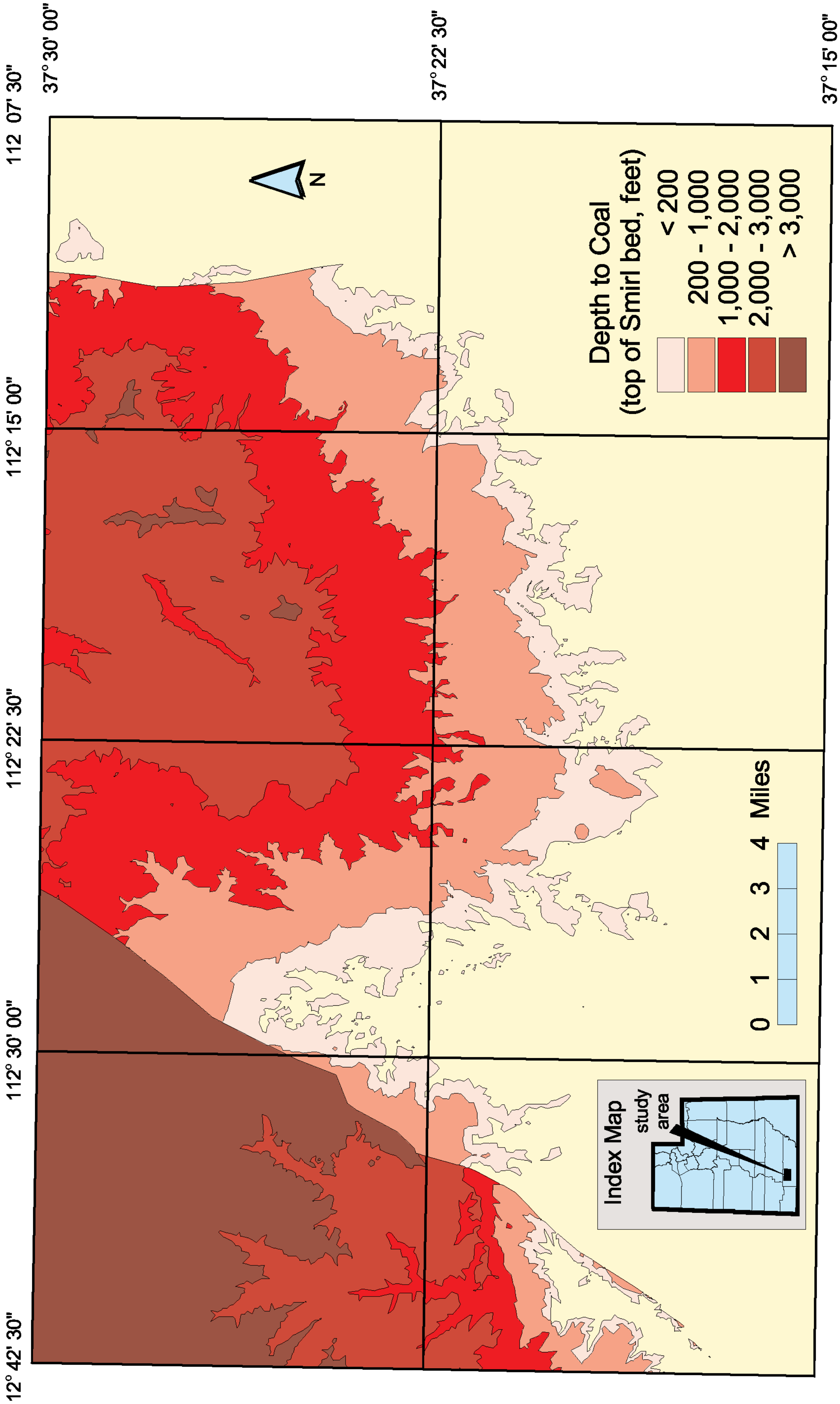

Figure A3. *Depth to top of Smirl bed, Alton coalfield, Kane County, Utah.*